TRANSFORMATION OF THE PHYSICAL ENVIRONMENT IN THE GREAT HUNGARIAN PLAIN, 1945–1985

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Motto: The physical landscape is the cumulative material and relief quality product of the paleogeographical events of previous periods. As a consequence, the quality of the physical region provides abundant information not only on its own evolution history, but also to the consideration of the validity trend and magnitude of the processes active in the landscape.

The Great Hungarian Plain of almost 100,000 km^2 area is a lowland enclosed by the Transdanubian Mountains, the Carpathians, the Bihar Mountains, the Southern Carpathians, and the Balkan massive and it was produced by crustal movements, infilling and planation over millions of years. The present surface is the outcome of a chain of past events in geologic and geomorphologic history. It is beyond doubt; the geomorphic natural agents, however, which were active in the past, have not ceased to exist, but, subject to the physical, chemical and biological laws governing them, they still operate and shape the surface in the present and will do so in the future too. In the assessment of the quality of the physical environment in the Great Plain, therefore, we have to take the natural trends of further development into account, which are independent of us and active in the sculpturing of the natural face of the Great Plain.

We, the inhabitants of the Great Plain, with our efforts to design and utilize the landscape according to our social interests, are frequently directly faced with spontaneous landscape development and sometimes we attempt to adjust it to our goals — both in the past and in the present. Our social decisions and actual re-functionalization of the landscape to our ends have resulted in new properties of the Great Plain landscape. All have been done to make the environment more comfortable and more productive of goods of consumption: channels were regulated, floods restricted by levees, channel lengths decreased, wetlands drained, the predominantly grassland with groves original vegetation removed, the network of canals for drainage and irrigation built, large reservoirs established, various technologies for soil amelioration developed, villages and towns with concrete surfaces built and chemical compounds, industrial, agricultural and transport wastes disposed in the pedological, aqueous and atmospheric environment and so forth. Thus, the Great Plain has become an anthropogenic macroregion by our days the development of which reflects the responses to social requirements manifested in more and more channels.

The human transformation of the landscape is, naturally, not characteristic of the Great Plain only, but a world-wide phenomenon and an inevitable corollary of socio-economic progress and technical development all over the world. In some countries and environments, the denaturization of the environment is of higher degree than in the Great Plain, in many countries of the Earth, however, our level of transformation has not been approached. We may not be mistaken to state that we are in a stage of nature transformation in the Great Plain when on the front between natural landscape forming agents and human reorganization of landscape functions, a battle was won in the short run, but we are unable to handle most of the feedbacks of the consequences apparent on the long run.

The aim of this paper is to present the major trends of landscape evolution which are as yet out of harmony with our targets and which, therefore, need more detailed investigations in order to elaborate a promising strategy against them.

The first group of topics of considerable importance to study is *the consequences of the present subsidence and the missing recharge of sediments in the area of the Great Plain*.

The distortions in the natural landscape dynamics of the Great Plain owing to human influence

The Great Plain is a basin subsidence of a Paleozoic–Mesozoic and crystalline basement which is compensated by the levelling effect of various sedimentation (locally and subordinately of erosion) processes.

This sedimentation was the permanent control of the subsidence of the basement and prevented it from resulting in an inland lake in the middle of the Carpathian basin which would have existed for a long period of time or would even have increasingly deepened.

The total volume of sediment accumulated in the basin since the late Tertiary and during the Quaternary enduringly exceeded the growth of the sediment recipient capacity of the geosyncline per time unit, although this latter was increased by the subsidence of the basement. Thus, in the balance of basin subsidence on the one hand and basin sedimentation on the other, at least over the last four or five million years, it is undoubtedly the rate of filling that was higher and sedimentation was the predominant agent in landscape evolution.

It is a rightful statement concerning the origin of the Great Plain that, although in the sculpturing of the details of the complex, multicomponent overall geomorphological picture, a vast number of Pleistocene, Early Holocene and Recent geomorphic processes (soil formation, alkalization, deflation and eolian accumulation etc.) were active, but all these geomorphic processes worked upon the material primarily transported and deposited by rivers coming from the encircling mountain watersheds to the subsiding geosyncline. It means that, although it is not always the rivers which organize and shape each detail of the visible landscape, the primary material was everywhere accumulated by fluvial processes and handed over to weathering, wind deflation, soil erosion, mass movements and frost action which agents created a wide range of forms.

The diversity of the Great Plain landscape necessitates the distinction between the natural processes which compensate the gradual subsidence of the geosyncline *by producing sediment* and the *local geomorphic* processes which may work upon the given material on the spot, select it and built up the landform elements complying with their nature. Therefore, in the genesis of the landscape *material providing* and *material processing* natural processes have to be distinguished. In this study the primary aspect of this system of relations, the origin and transport of material is investigated.

The thickness of fluvial sediment differs with the various parts of the Great Plain, but it is considerable everywhere. The sediment sequence including the 2 million years of the Quaternary is only 40 to 50 m deep in some regions, but in the partial geosynclines of more dynamic subsidence it reaches thicknesses between, 400 and 500 m. According to the detailed analysis of the Dévaványa borehole, for instance, the Pleistocene/Levantan boundary is placed at 450 m depth. It means that the rivers which deposited their load here were able to accumulate material in compensation of (450,000 per 2,000,000 equals) 0.225 mm per year subsidence (more than 20 mm per 100 years) and it equals to deposition of 225 m^3 per km^2 per year.

It is noted that some authors (URBANCSEK, J. and RÓNAI, A.) estimate an even thicker Quaternary sequence, up to 800 m (!) locally.

As matter of course, there are sections in the Great Plain where no considerable sedimentation took place during the Quaternary. These sections are mostly coincident with areas where no remarkable basin subsidence is known from the Holocene, while in other areas, particularly in partial basins of fluvial fill, the constant further deepening at various rate from place to place of the basin was the predominant agent in the origin of facies.

The map of validity trends of spontaneous natural geomorphic agents in the regions of the Great Plain is presented in *Fig. 1.*

This map well illustrates that the predominant geomorphic agent over the major part of the Great Plain surface is fluvial accumulation which operates through the deposition of sediment load deriving from the adjacent mountain watersheds. In the meantime, they permanently changed their courses as well as the main direction of their flow. This fluvial deposition was rapid enough to keep pace with the subsidence of the Great Plain at various rates and, consequently, the surface of the macroregion was always filled to produce a level plain.

The above formulated close relationships between landscape quality and the energies spontaneously active in the landscape were the exclusive controls of evolution even before 200 years ago — but they no longer are. It is because Man appeared with his sweeping dinamics in landscape evolution and human society, with its techniques made more and more efficient in an exponential way, neutralizes

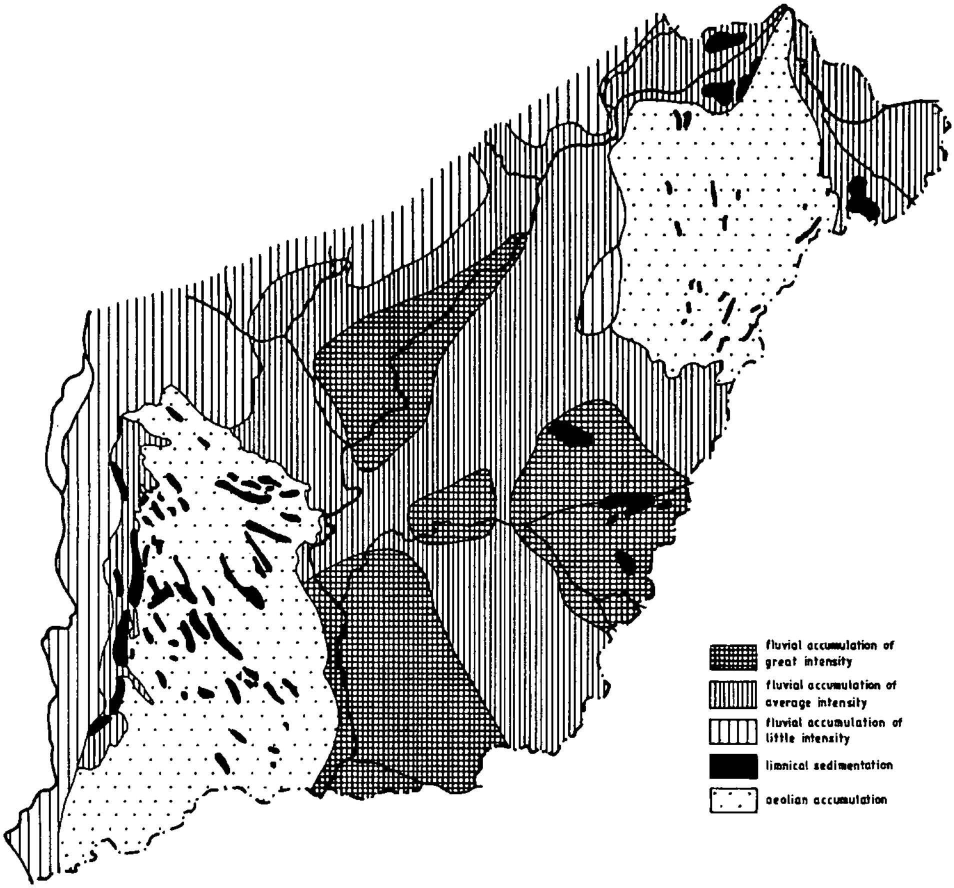

Fig. 1. The regional distribution of the most important quaternary landforming factors on the Great Plain (L. Jakucs)

the genetic processes of previously rather prolonged existence to a degree increasing decade by decade. Human impact on the landscape produces not only new elements, but it is an active brake or regulator of landscape energies.

The true extent of the efficiency to stop and reorganize spontaneous landscape energies is not easy to estimate for the Great Plain. Even professional opinions are directly opposed in this point. Thus, there is no place for any subjective opinion based on speculation. Instead, aspects and methods founded on unambiguous measured data have to be sought which reveal the interactions of truly objective tendencies and facts.

In order to estimate the impacts of human interventions like river regulations and flood prevention measures as well as the drainage of marshlands and the transformation of natural vegetation in the Great Plain in an objective manner, the map of regional distribution of the present (20th century) physical geomorphic agents

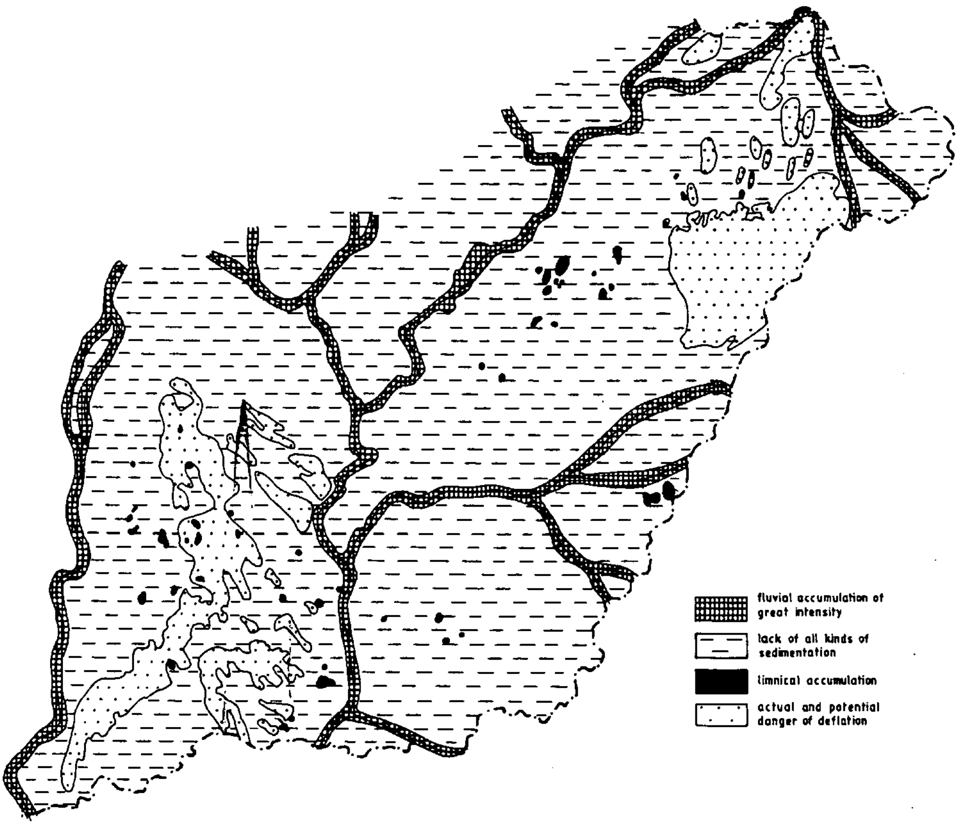

Fig. 2. The regional distribution of the most important recent (XX century) landforming factors on the Great Plain (L. Jakucs)

in the Great Plain landscape was drawn (*Fig. 2*). On the map we intended to represent the same landscape factors as in *Fig. 1* in order to point out the most important differences through the comparison.

When comparing the two maps of the same area, the following become evident:

1. In the areas of intensive fluvial deposition on the first map, fluvial accumulation has practically ceased by our days and rapid sedimentation is restricted to the narrow linear strip of active flood-plains between levees along rivers. Here a *major areal constraction and shift* of one of the most remarkable of the landscape processes in the Great Plain is observed. Our calculations show about 85 per cent loss in this category of landscape factors and it means that *over about 85 per cent of the most rapidly subsiding areas of the Great Plain, the lowering of the surface at relatively high rate is essentially uncompensated for by any process.* These dangerous symptom groups and their consequences will be tackled in detail later.

2. In the areas of fluvial accumulation of low to medium intensity there is *no* fluvial sedimentation and, therefore, these categories of landscape genesis could not be represented in their areal distribution in *Fig. 2.* It is evident that in areas described as having fluvial accumulation of low to medium intensity in *Fig. 1*, subsidence also takes place, altough at a much slower rate than in regions mentioned at point 1.

3. New areas have become affected by fluvial and partly by lacustrine accumulation of high intensity in the reservoirs dammed up artificially. In some of them filling is so rapid that they lose much or all of their storage capacity by siltation within a relatively short period of time unless the process is efficiently reduced by labour and cost intensive channel or lake bottom dredging.

4. The areas which were formerly characterized by active eolian accumulation and reworking have been considerably reduced in extension or even disappeared in the Great Plain which is due to forestry and agriculture (vine plantation etc.) where surface stabilization is included in the plans. This change in landscape evolution is obviously assessed as a favourable trend for society in perspective. In some regions, first of all in the Danube and Tisza Interfluve and in the Nyírség, potential or actual deflation still has to be taken into account.

5. The extension of lowland, areas formerly affected by lacustrine and paludal accumulation has remarkably been reduced in Hungary and it is further decreased by the contraction of open water surfaces accompanying the process eutrophication in decaying natural (and artificial) lakes. The evaluation of the process from an economic viewpoint is only feasible through the confrontation of the sometimes considerably opposing requirements of various sectors (fishery, agriculture and tourism and so on) of the national economy.

6. In the sections of the Great Plain where the dynamics of accumulation is of low to medium intensity during the Quaternary in *Fig. 1*, *today* areas with interrupted deposition are typical and extended where there is no accumulation in our days, almost exclusively as a consequence of the flood control measures implemented *(Fig. 2)*. In these spots the lowering of the surface continues and this initially promotes the rise of groundwater table and subsequently involves the spread of excess water.

7. The extension of areas described by erosion or deflation have locally decreased considerably (e.g. in the sandy portions of the Danube-Tisza Interfluve, in the surroundings of the Gödöllő Hills or in some zones of the Nyírség sandy region). These phenomena may also have anthropogenic reasons well interpreted from place to place. Generally, however, these not too significant changes in the landscape can be controlled by planning in the Great Plain.

If the message contained in the above check-list is further analyzed, a more detailed investigation has to concentrate first of all on the major areal restriction of fluvial activity in the landscape.

Measuring the areas of intensive Quaternary subsidence in the Great Plain, at least 20,000 km^2 is found for the extension of the geosynclinal zones where the Quaternary sedimentation reached the thickness of minimum 300 m. Of the same area are those parts with 150 m average thickness of Quaternary series. The areas of Quaternary series of small (20–50 m) thickness are not considered here.

It is to be noticed that the values are cautious estimates and rather underestimates and Hungarian geological and deep borehole data would justify their rise even by 50 to 80 per cent. Although our caution may be exaggerated, we insist on the above figures and even in this case striking data are given for the amount of Quaternary sediment in the area of the Great Plain. The results of the calculations are the following: in about 40,000 km^2 of the macroregion $9x10^{12}$ m^3 (9,000 km^3) sediments were deposited during the last two million years. It means 4.5 million m^3 sediment per year, which is a high figure.

The thought cannot be avoided, however, that river regulations and flood control measures have proved ineffective from the viewpoint of erosion dynamics in the mountainous watersheds of Hungarian rivers. It means that the rivers reaching the Great Plain continue to transport the same load per unit time to the lowland and the sediment is mostly deposited where it can, on the active flood-plain. The lowland active flood-plains of the major Hungarian streams, however, are of about 400 km^2 total area only.
Thus, if the load of the rivers deposited according to the ratios in the Quaternary, the above estimated 4.5 million m^3 of sediment would be deposited in the highly restricted active flood-plain, it would mean an annual 11.25 mm thickness of new sediment on the average. These overbank sediments, however, never accumulate in layers of even thickness over the whole surface of the active flood-plain, but are concentrated in particular sites. This is the danger inherent in them as in some sections these sediments may considerably reduce the discharge capacity of the channel. Consequently, levees have to be raised constantly to the point when the river itself flows along the axis of a somewhat elevated ridge enclosed between dikes. Along some Great Plain reaches of the Hungarian Danube valley the bottom of the flood-plain enclosed within the system of levees lies 3–4 m above the terrain outside the dikes and, as a result of recent alluviation, it naturally continues to rise. According to the report of the River Hydrology Department Institute of Hydrography for 1983, along the Kisköre southern national border of the Tisza river, the bank zone has been raised an average 30 cm during the last six years, in spite of the deposition of the majority of solid load in the enormous main basin of the Kisköre reservoir and, thus, the downstream section is highly relieved of load. Sooner or later, the Great Plain stretches of Hungarian rivers will share the fate of the river Po, the channel of which, as it is well known, has reached the level of church spires at Ferrara.

The situation is more favourable, as a matter of course, than the calculated for the siltation between the levees. The surges restricted within dikes have much shorter residence times than before flood control measures when during major floods peak discharges caused the inundation of more than 25 per cent of the area of Hungary (24,000 km^2) and the waters, which at last became stagnant, deposited all of their sediment load. As a result of the present shorter residence time, the depositing part of sediment is at least 20 per cent less today than before the regulations.

Nevertheless, it is still observed that siltation is too rapid within the levees. After major flood peaks several cm or dozens of cm thick silt layers are left behind since, as it has been mentioned, siltation is commonly concentrated, i.e. silt veneers of uneven thickness result in the active flood-plain. As a result of this process, along most of their reaches, active flood-plains are elevated even today, the youngest alluvial flood-plain sections lie higher than the older ones. This phenomenon is unnatural and reflects the recent inversion of accumulation levels. All these are adverse influences for us since the cross-sections of the active flood-plain designed to let floods through are reduced time after time and *flood hazard gradually increases* and, if the process is not blocked, it can be delayed only by considerable dredging and raising the dikes.

The above are supported by measurements in Romania. The average figure for specific erosion on the watersheds of the left-hand tributaries of the Tisza is 1 t per hectare per year, i.e. runoff removes an annual amount of 40 m^3 soil and rock waste from each square km of the watershed (calculating with 2.5 sediment density) and the material is transported to Hungary. The total catchment area of left-hand tributaries is 61,890 km^2 and considering this partial watershed 2,475,600 m^3 sediment arrives to Hungary annually.

As a matter of course, in the dynamics of the accumulation of alluvial fans and flood-plain deposits, not only human influences (flood control) and not only the alternation periods of relative accumulation and erosion reflecting the movements of the geosyncline basement are manifested. Besides these important determinants, the varying *amount of relative sediment load* of rivers was always a decisive qualitative and quantitative control. This relative load varied with the *denudation (sheetwash erosion* and *soil erosion)* rate and efficiency modifying with time. This factor of load regulation (sometimes delimiting cycles of sedimentation and the periods of erosion alternating with them) is well known in the Hungarian literature from the *terrace studies* of BULLA, B. and PÉCSI, M., also for the Great Plain.

It is first of all *climatic change* that induces the major alterations of proportions in the sediment transport of rivers during the last millions of years. The capacity of rivers to transport sediment is controlled by the properties of *weathering* (highly susceptible to climate), *mass movements* and *changes in precipitation intensity*, modifications in *evaporation and temperature* as well as the *vegetation cover* of the catchment closely related to all these factors. Broad limits are thus defined and the stream may erode its channel in one period and cut into its bed deposits and, along the same reaches, may silt up its channel in another period — depending on climatic properties. The balance of sediment transport of a stream may shift from the 'upper reaches' type to the 'lower reaches' type or be transformed in the opposite direction — induced purely by climatic change. This was the reason why BULLA, B. interpreted the present face of the Great Plain as a *polygenetic macroregion* which is „the result of the Pliocene, Pleistocene and Holocene tectonic movements, Upper Pliocene and Pleistocene fluvial erosion and accumulation (spreading alluvial fans), Pleistocene alluvial fan accumulation and solifluction (cryturbation), Pleistocene deflation and loess accumulation, interstadial and interglacial linear and areal (sheetwash) erosion and accumulation, postglacial loess accumulation, erosion and deflation as well as recent weathering, mass movements on slopes, fluvial erosion and accumulation which alternated, supported or counteracted each other's effect."

All this diversity in geomorphic evolution became manifested in the face of the Great Plain only long periods of time. Of the factors tackled a single system of interactions must be emphasized and it is so rapid that during some decades of the Holocene has produced very unfavourable consequences. It is the *subsidence of the surface which became uncompensated for in the Great Hungarian Plain.* In the following some practical dangers resulting from this subsidence are dealt with in more detail.

Trends of groundwater conditions in the Great Hungarian Plain today

My results unambiguously support the findings of hydrogeologists (Rónai, A., Somogyi, S., Urbancsek, J. and others) that the flood control measures, river regulations and the establishment of irrigation canals as well as landscape transformations associated with urbanization, new agricultural technologies and extended infrastructure have not only led to the large-scale alteration of the surficial drainage network, but heavily influenced the quantitative, qualitative and hydraulic properties of *subsurface waters.* In short, landscape reorganizations resulted in new hydrogeological conditions in the near-surface layers of the Great Plain and this transformation is even accelerating today.

In the substitution of the former groundwater conditions with new ones, the following ways of human intervention have been (and still are) of decisive importance:

a. Shortening the lengths of streams and the related overdeepening of mean water channels.

b. Increasing flood levels in the amphibiotic flood-plain zones.

c. Elimination of the waterlogging which had affected large areas before the flood control works.

d. Drainage of former natural swamps and marshes by canals.

e. Increasing utilization of groundwater in many places.

f. Establishment of dammed reservoirs of raised water table and other artificial lakes.

g. Construction of irrigation canals in the Great Plain and the general spreading of cultivation with irrigation.

h. Substitution of natural plant associations with different, mostly agricultural crops.

i. Transformation of soil structure by cultivation techniques of various efficiency: partly mechanical techniques (soil loosening and compaction, deep ploughing etc.) and partly chemical interventions (fertilizers, herbicides, pesticides, etc.) belong here.

j. Increasing losses of soil surfaces as a result of urban sprawl and developing transport network (concrete surfaces, built-up areas, public roads etc.).

k. Last but not least, the landscape ecologial alterations in the watersheds induce changes in the regime of streams.

Unfortunately we are not as yet in the position to determine the validity mechanism and magnitude of each of the mentioned factors controlling groundwater, since we are only able to outline the cumulative result of the multifarious effects exerted parallel to each other. Therefore, we can only undertake the *general impacts of groundwater control* due to the complex operation of various agents or notice the *decisive role* of one factor or another within a partial unit of the area investigated. It is not to be ignored, however, that in water budget of soils and also in the chemical properties of groundwater, progressive and regressive processes may operate simultaneously and they often counterbalance each other.

Below, the present controls of groundwater conditions in the Great Plain are investigated in detail.

The *shortening* of *river channels by cut-offs* has exerted a considerable influence on the fall of groundwater table even in the broader environments of rivers. The relationship is explained by the increased slope of the river bed which resulted from the shortened channel. The Tisza river, for instance, was 1211 km long in the reaches affected by the regulations and it shortened 453 km during the regulations and it is only 758 km today (38 per cent shortening of the lowland section!). Consequently, general slope grew almost twofold (3.7 cm per km before and 6 cm per km after the regulations).

It is the same situation with the main tributaries of the Tisza. The 187 km long regulated section of the Szamos river contracted into 108 km and the Hungarian section of the Bodrog river from 76 km to 56 km. The shortening of the channel was the highest in proportion in the case of the Berettyó river, 269 km of this river was regulated and, as a result, its length was reduced to 91 km. The same figures for the White Körös: from 126 km to 67 km, for the Black Körös: from 166 km to 90 km and for the Swift Körös: from 162 km to 86 km. Thus, the slopes of these rivers grew.

As a natural consequence of the rise in slope, the channels of these rivers deepened and low water levels considerably fell. This resulted in the fall of groundwater table during periods of low water (adjusted to the axis of depression along the streams) and this induced the increased flow of the adjacent groundwater towards the channel. Groundwater table in the affected zones fell and this brought about the appearance of symptoms of drought in the river-bank zones, since low water dominates during most of the year. It is manifested in the decay of riverside forests and the change of microclimates in flood-plains towards the continental type.

Consequently, channel downcutting after the river regulations and the construction of canal networks lowered groundwater table over a large part of the Great Plain and, thus, the area of agricultural land with drought requiring irrigation has increased. It was partly due to this fact, too, that

a. leaching intensified in the soils of the Great Plain, as from the top horizons precious nutrients are removed into the deeper horizons and

b. the inclination to alkalization grew, as by irrigation the cultivated areas are supplied with some non-desirable dissolved salts through the canals. The water in the reservoirs, cut-off channels and main drainage canals most heavily exploited for irrigation becomes concentrated and water quality may deteriorate, particularly during the summer, when, in the principal season of irrigation, evaporation and dissolution of salts are intensive. Then the ratio of dissolved calcium and magnesium salts to sodium may shift in an unfavourable direction from the viewpoint of irrigation. In our living waters this ratio is around 3 to 1, while the water of the Hortobágy–Berettyó and other large drainage canals and reservoirs have ratios of 1 to 1 or even worse. In these circumstances irrigation water has an alkalizing effect.

The remarkable rise of flood levels in the seasonally wet flood-plains has, as a matter of course, an opposite influence on the groundwater budget of flood-free plains. The raised water levels between the dikes are well above the soil surface today and, thus, the highly increased hydrostatic pressure of overbank discharge reverses the direction of groundwater flow and, particularly in near-surface layers of coarse deposits, a rapid spread of groundwater results. All these, of course, raise the groundwater table and may lead to excess water formation, which has been a severe problem in water management and agriculture for a long time (waterlogging of soils, drowning of roots etc.).

The message can be summarized as the beds of the Great Plain rivers are followed in some km width by a zone of high range of groundwater and its characteristic fluctuations of water table are controlled by the regime of the rivers to a decisive degree. The zone has a width of 4–8 km and even more in places.

The width of the zone of groundwater subsidence partly reflects the water conductivity of the sediments at shallow depths along the river channels and also the fact that lateral groundwater recharge is not entirely controlled by the channel, but locally groundwater flow of extended surface area also exists *in the alluvial fans* and the peaks of this latter flow follow the high waters of the river with a considerable delay and in the actual water levels here the interferences of the different phases are also manifested.

The elimination of waterlogging in extended areas (flood-plains before the regulations) and *the drainage of former swamps and marshes by canals* have both resulted in the fall of groundwater tables in the areas affected. These hydrological regulations had far-reaching hydrogeological consequences as before the start of flood control works, waters left over by floods covered about 3,988,000 cadastral acres of land almost permanently. Another 2,737,000 cadastral acre is to be added to this figure since it was seasonally inundated. It means that about 24 per cent of the area of Lowland Hungary below 200 m above sea level was flooded permanently or seasonally.

One of the main reasons for wide-spread waterlogging was the divertion of streams of gentle slope and low current velocity by even the smallest obstacles and, consequently, they often changed their courses. The rivers entering the Great Plain from the mountains deposited vast amounts of sediment and on these alluvial fans of loose material streams easily eroded new channels — more and more by-channels resulted. During overbank flow the sinuous rivers deposited their load mostly along their banks and built up low ridges (first point bars which were later transformed into riverbank dunes) and these ridges blocked the flow of excess waters back to the living channel from the lower and more remote parts of the flood-plain.

Another factor promoting the subsidence of groundwater table today is the *increasing utilization of groundwater.* Particularly in portions of the Great Plain (in the settlements) which are long distances away from streams and even canal networks are not adequate to supply them with water, more and more water is pumped both from near-surface aquifers and from deeper lying strata. This increassing exploitation of aquifers leads to the *permanent decrease of static water reserves in aquifers* and groundwater more easily recharged are sinking and *centripetally flow towards the centres of extraction.*

Centripetal flow itself is no reason for worrying. However, in many places it involves the concentration of groundwater contamination originating from remote agricultural regions in the foci of extraction and the rapid deterioration of water quality in the urbanizing areas. At the same time, in the direct vicinity of some Great Plain (and particularly Trans-Tisza) settlements tendencies of excess water expansion have intensified as a consequence of the fact that the establishment of drinking water conduit network was not accompanied by the construction of sewage canals and the waste water deriving from the increased water consumption cannot be disposed of in the villages. A similar situation arises with the water issuing from thermal water wells; it has been accumulated by now in extended excess water lakes in some places such as in the area of the Termál Cooperative Farm in Szentes.

The establishment of dammed reservoirs of raised water level and other artificial lakes may also have a positive effect on the water budget of soils. The primary agent here is the influence of the increased and permanent pressure of water column inducing infiltration which, however, after a while (especially in the case of shallow and silty Great Plain lakes) leads to the decline of percolation at the lake bottom, since organic and colloidal products may seal the pore spaces of the topsoil and, thus, an impermeable layer may result at the lake bottom. Some bioecological properties may decelerate this process and others may accelerate it. There are considerable differences, however, in the rises of groundwater table observed after the damming of the Kisköre reservoir and the Hortobágy fish-ponds; it results from the lithological properties of the subsoil. It appears that the reservoirs which include sections of the recent river channels are more efficient in raising the groundwater table than the reservoirs built on the alluvial flats of older flood-plains.

The supply of the Great Plain with an irrigation canal network and the general spreading of cultivation with irrigation naturally does not only improve the water budget of the fertile layer, but a good proportion of the irrigation water, particularly in soils on sand or loess, reaches the deeper soil horizons and becomes the factor of local groundwater rise. This influence will be the prominent source of groundwater recharge on higher-lying terrains of the Great Plain where conditions are not favourable for seasonal waterlogging and where the original water table was low too.

In a morphogenetic sense, particularly in the margin of the Great Plain, on the alluvial fans of the Körös and the Maros rivers, the sandy series point to channel deposits or the related flood-plain deposits (point bars), although they may also indicate asynchronity in the genesis of sediments associated with different climatic (precipitation) conditions. Further information is needed to decide definitely whether the axes of concentrated infiltration also increased by irrigation water coincide with the foci of centrifugal groundwater flow.

The substitution of natural vegetation with various plants, mostly with agricultural crops are also factors inducing remarkable changes in groundwater conditions. The whole Great Plain belongs, in a cenological plant geographical sense, to the belt of steppes with groves and it was covered mostly by forests and meadows before the advent of regular crop cultivation. Human intervention turned them into cultivated steppes and even where the surface was not used for purposes of intensive farming or gardening, natural vegetation has undergone major transformations. In such places loess steppes, forests on sands and flood-plains as well as the meadows of sand and loess surfaces, in the places of the previously extended marshlands and swamps, wet meadows with Molinia coerulea, reed-beds, high sedge stands or swampy meadows are found. The area of alkali steppes has also grown as a result of the wide-spread drainage works.

Today the natural vegetation of the Great Plain is characterized by the predominance of deciduous tree species which favour light, are tolerant to extreme temperatures and of medium water need and locally euryhaline species also occur. In the cultivated vegetation arable land and row crops as well as orchards and gardens are typical. In addition, semicultivated grasslands are of large areal extension.

The substitution of the natural vegetation with plants more valuable for the society, as a matter of course, involved rapid changes in the quality of soils and their water budget in the Great Plain. The most minute studies of this process in Hungary were written by Stefanovits, P., Szabolcs, I. and Somogyi, S. In their opinion the spreading of cultivated steppes began as early as the Middle Ages with the removal of marginal forests and their cultivation. In those zones typical brown forest soils were preponderant. The clearing of forests and the farming of land induced changes in microclimate and the heat and water budgets of soils which became manifested in the elimination of the forest soil character and the intensification of chernozem dynamics.

Due to the effect of the large scale flood control measures and river regulations in the last century chernozem dynamics gained in power, since groundwater table remarkably subsided at the higher levels of flood-plains. Rapidly spreading farming transformed meadow and boggy soils and most of the raw alluvial soils into meadow chernozems of transitional type, and, thus, it added to the area of older chernozems. In spots of still high groundwater rich in concentrated dissolved salts, various types of alkali soils formed and were preserved in the depressions without drainage. Finally, part of the former permanently waterlogged surfaces retained their high groundwater table even after the drainage measures. Thus, a new distribution of meadow soils resulted with the more or less serious hazard of alkalization.

The transformation of soil structure through cultivation methods of differenct efficiency has become another major control of groundwater budget in the Great Plain. The infiltration capacity of any Grean Plain soil types is highly dependent on the degree of compaction of the soil surface and the depth of clay illuviation horizons below the surface.

The cultivation methods including the various techniques of ploughing and other soil loosening exert a regulating effect on water budget and increase the water retention capacity of the fertile layer which promotes, in most of the cases, the rise of groundwater table. Nevertheless, there are technologies such as the compaction of the base of the ploughed horizon which hinder the recharge of water into the deeper horizons from above, since these compact layers almost insulate the uppermost ploughed horizon at its base. As a matter of course, much depends on precipitation and evaporation too.

The use of fertilizers and other chemicals in the various branches of agriculture also influence the long-term infiltration capacity of soils and, even to a greater extent, the chemical properties of groundwater through incidental loading. Our investigations allow the conclusion that in some smaller groundwater districts the percolation of sewage from the oil industry may also modify the sodium and chloride ion concentrations of groundwater. The growth of chloride content in groundwater, particularly for coarse sands of high permeability, is observed as much as some km away in the direction of flow from the site of pollution. The growth of NaCL in groundwater as we observed it was not harmful to water quality in any case, since this is not a dangerous chemical and given the large-scale dilution, this may only be a theoretical issue. In contrast, the local anomalies resulting from chemical techniques are much more marked in agricultural areas.

The next governing factor of groundwater table, which is gaining in importance today, is *the loss of free soil surfaces caused by urban sprawl and the construction of up-to-date transport networks*. This characteristic group of symptoms of civilisation has a net effect of the restriction of former natural paths for groundwater recharge and leads to *'ebbing groundwater'*. The influences are the following: built-up areas, spreading concrete and asphalt surfaces, public roads with insulating pavements and so forth. They are spreading in area and the sealed surfaces do not allow any infiltration. Precipitation onto these 'human' surfaces partly evaporates and mostly feed runoff along artificial canals and reach the living streams, i.e. they are lost from the viewpoint of the groundwater budget in the area.

The tendency of groundwater reduction in the settlements is increased by *the great demands of water* the considerable proportion of which, especially in rural areas, is satisfied from the local reserves of groundwater in most parts of the Trans–Tisza region.

Last but not least, *some changes in stream regimes induced by the landscape ecological transformations on the mountain watersheds* have also began to influence the new groundwater properties to a considerable extent. Particularly the tendencies of more intensive utilization manifested in the pattern of vegetation and soil cultivation such as *canalization, channel regulation and cultivation changes* along the upper sections of streams, in their cumulative effect substantially increased the *runoff ratios of rainfalls of continental type*. After the clearing of natural forests and, especially of deciduous forests, infiltration and evaporation on slopes was reduced to a fraction of their original values and this remarkably increased the peak discharges and also the annual mean discharges of streams recharged from these areas. This involves that streams of higher discharge provide more groundwater in the layers stretching along the river channels, particularly in the area of the extended alluvial fan series in the margin of the Great Plain. For this reason, from the direction of the alluvial fans *the centrifugal flow of groundwater* increases towards the more remote parts of the Great Plain, although it is undoubted that this effect is shown in the rise of groundwater table with a considerable, sometimes even a year's, delay. This delay is a natural consequence of the slow motion of groundwater, which flows in aquifers over a table of little convexity and it is also clear evidence of lateral throughflow replenished from the stream channels and flood-plains.

Through an indirect feedback *the siltation of seasonally wet flood-plains* may also result in the rise of groundwater. This siltation reduces the planned bankfull cross-sections of flood-plains year by year. The reduction of the cross-section and the necessary raising of dikes increases flood levels and, thus, leads to a greater infiltration inducing hydrostatic pressure.

After the overwiew and interpretation of the major recent controls of the properties, flow dynamics and chemical composition of groundwater in the Great Plain (some increasing and some reducing groundwater reserves), it has to be repeated that today we are yet unable to determine the proportions the individual factors are responsible to the cumulative outcome of influences. The complex *end products of the cumulative partial factors manifested as a tendency* can be observed. The most important of them are the following:

1. Over the largest part of the Trans–Tisza region a slow rise of groundwater table have been observed for about 30 years. This rise, however, cannot be associated with mean annual precipitation since the change of this latter does not have a net rising trend.

2. At some groundwater gauges of the VITUKI (Research Institute for Water Management) to the mean regional rise of groundwater remarkable surplus rises have been added since the mid-1960s. The 'added values' are observed in all seasons alike, but they do not reflect local mean precipitation.

The general rise of groundwater, in our opinion, reflects the joint impact of the following major factors:

a. the surface subsidence observed over practically all of the Great Plain;

b. the influence of the seasonal sedimentation by streams on their flood-plains;

c. the trend of increasing total discharges and flood levels of streams;

d. the areal growth of artificial lakes and reservoirs;

e. the areal expansion of irrigation networks and irrigated lands;

f. the substitution of natural vegetation with cultivated crops;

g. the consequences of changing cultivation methods in farming (e.g. the increased long-term infiltration coefficient induced by the spread of deep ploughing).

It is our hope to promote long-term forecasts and plans for optimal land use in the Great Plain with the demonstration of the above systems of interaction. as a matter of course, today it is not easy to forecast natural landscape trends, since the 'purity' of natural landscape forming agents characteristic of their mechanism and spreading in prehistoric times does not exists any more. At the end of the 20th century no 'untouched' natural landscape is found in the Great Plain that has not been affected by human intervention, in most of the cases in a very effective way. This was the advent of *intricate relationships of the factors of landscape evolution* which is observable in the joint operation of spontaneous natural and accelerated human landscape forming influences, their interactions, the upset of the former ecological balance of the landscape, and in something entirely new, the enforcement of the anthropogenic geographical system, a rational one, which is capable to function in the totality of the expanded set of interactions.

It is regrettable that in the elaboration of the main targets and provincial counter-centres of settlement development and industrial allocations, the requirements of long-term optimal landscape use often remain unsatisfied. The preservation of the original values of air, soils and waters and the conservation viewpoints of no longer tolerable landscape ecological chain reactions of more indirect feedback do not always have the proper prominence in the plans and this is explained by economic reasons or simply by ignorance. It often happens that predictable multifarious deformations of the environment caused by the artificial landscape of a man-made object, some project are only considered in the short run or with subordinate significance. After a while it becomes evident that some deformation of the landscape function due to the denaturation of an ecological feedback endangers the further development of society or even the attained social standards. It may be too late to fight the damage manifested through several indirect relationships in hope of success. On such occasions, it is only after completion that the need for more comprehensive and long-term geographical or environmental (landscape ecological) forecasting for regional development becomes evident.

The human implications in the increasing extremes of the water regimes of streams in the Great Plain

In addition to the above outlined systems of influences, mention should be made of the reasons behind the more and more characteristic extremes of the regimes of the Great Plain streams. These extremes are mostly motivated by the rightful growth of human requirements against the landscape and the spreading of more and more demanding crops. It is a justifiable national intention, for instance, that in Romania more and more bread corn should be grown for the people, but our troubles in flood control also spring from the same efforts. For the above reasons, in the mountain watersheds of Hungarian streams flowing from Romania, *the runoff coefficient of sudden rainfalls* increases abruptly and, as a corollary, the *sediment load* of flood discharges also grows. Let us inspect why?

It is called into mind that the regime properties of streams are determined y the precipitation on their watersheds. It would be a major mistake, however, to equal the amount of precipitation to the discharges of rivers or to postulate a direct proportionality of no disturbance between them. In fact precipitation is only one among the factors of rivers regime, since numerous other governing factors claim their role in different places and periods.

The catchment of any rivers can be subdivided into a mosaic of partial catchments of highly different runoff coefficients. Within the drainage basin of the Tisza river there are areas with long-term average runoff figures of less than 2–3 per cent of the average precipitation of many years, but there are others where as much as 40–50 per cent of the precipitation feeds runoff into the river channels.

During our investigations we studied the annual runoff coefficients of some partial watersheds in several years. It was found that the regional runoff coefficient data collected in literature can only serve approximate orientation. In the various mosaics of the landscape, the runoff coefficient changes with time and even the proportions between neighbouring spots may reverse. The reason for this controversial phenomenon is the dependence of runoff coefficient on the cumulative effect of a vast number of variables.

Among the variables the most important are the amount and nature (snow or rain) of precipitation, its seasonal distribution, the duration of dry spell between consecutive precipitation events, the intensity of rainfall and the interactions of all these factors with the changing temperatures and winds and with the actual humidity of air. The ratio of frosty to frostless periods, their interferences with periods of precipitation and with the date of thaw in various combinations and the indefinite variations of correlation between the above factors and vegetation density and the varying degree of soil cultivation are all of equally great importance in the intraregional differences of the annual runoff coefficient.

All these temporally variable governing factors combine to produce a twofold or threefold higher runoff coefficient in a given site in one year than in another with similar total precipitation. For this reason, a really reliable map of runoff coefficient could only be drawn if long data series of (50–100) were available for the surfaces of each of the minor partial watersheds, but this would naturally be an unsatisfiable requirement in the future.

In the system of the agents which regulate regional runoff coefficient, the group of anthropogenic (human) factors is essential and of *unidirectional progressivity*. Therefore, special attention was directed to the landscape forming activity of *human society* in our investigations of the catchment of the Tisza river. Human intervention was primarily studied in the feedbacks of *influences on the vegetation cover of mountain watersheds* on runoff magnitudes.

In our investigations preference was given to watersheds of mountainous relief for the reason that this factor is of no remarkable importance in lowland catchments of low relief. In the portion of the Great Plain along the Tisza, for instance, where annual average precipitation is 600 mm and annual potential evaporation is up to 700 mm, there is no runoff worth mentioning and the situation would be the same even if the whole of the Great Plain were covered by forests. In the mountainous watersheds of the Tisza river, however, particularly in the Northeastern Carpathians and in the upland regions of Transsylvania, the amount of precipitation is 10 per cent to 50 percent higher than the figure for potential evaporation. The actual proportions within the limits are most dependent on the quality of vegetation cover and the related soil categories.

The characteristic hydrological phenomenon of our days, *the shift of the types of river reaches* of lowland rivers towards the types of lower reaches character. Our assumption is founded that one of the causes of this annoying symptom present along the Hungarian streams to various extent is the landscape transformations of the mountainous watersheds, the substitution of the original vegetation which had ensured the natural balance of landscape dynamics with crops more valuable for society. All these activities of nature transformation, through the human alteration of soil structure equivalent in influence to relative relief, mostly lead to large scale *soil erosion* and largely increase *the load of streams*. Thus, where the streams were of middle reaches type (as their capacity equalled the energy necessary for the transport of sediment), they tend to deposit, fill their channel, silt up their flood-plains and build rapidly accumulating deltas and alluvial fans on their confluential or lowland reaches. This is a dangerous phenomenon, partly because of the increasing *residence time of floods* in the streams of slowed-down flow among shoals and along by-channels and partly because the cumulative flood discharge grows.

Regrettably, in the plans for regional development a typical feature of our days is hardly taken into account: the more and more intensive agricultural utilization of originally forested areas considerably increases the runoff coefficient of *mountain watersheds*. This may give rise to a manifold increase of discharge and the absolute amount of the removed soil and debris, mostly on the lower river sections lying in long distances from the catchments. This topic deserves more attention than it has today.

As it is known, the influence of vegetation on the runoff/evaporation ratio is exerted through two channels:

a. Vegetation (and particularly deciduous tree vegetation) promotes the formation of soils of looser structure than those on open surfaces and, in this manner, forest associations increase the permeability of soils and reduce their runoff coefficient.

b. On the other hand, however, besides this direct influence, another direct one also exists which is the dynamic factor expressed in the resistence of vegetated soils against erosion. In forested areas, where litter accumulated of decayed branches and leaves, the intertwining of root systems adds to the resistance of the soil surface against erosion and also accelerates infiltration and promotes the longer preservation of soil moisture. Through these mechanisms it reduces runoff and increases the loss of water by evaporation.

The above factors do not have equal importance all over the drainage basins. Their influence depends on the density of vegetation, on the closure of foliage, on the depth and maturity of the litter horizon, on the structure or lack of undergrowth and also on numerous circumstances not detailed here. Nevertheless, according to the experts engaged in the study of this topic, the extent of the runoff regulating influence of vegetation as a whole may reach *the magnitude of the joint effect of all the other factors* which govern runoff.

Suffice it to cite only one example for this. In 1979 in the Mátra Mountains we experienced a summer shower of 6 mm 50 per cent of the water of which flowed down the barren slope as immediate surficial runoff, while on a slope of similar inclination and soils, but covered by contiguous deciduous forest no surficial runoff was observed.

For the above reasons, any human intervention which affects *the density of flora* on the surfaces of mountainous areas is of the utmost importance. It most often occurs that natural forests are succeeded by agricultural crops more valuable for society.

In this respect, unfortunately, the trend refers not only to the catchment of the Tisza river, but the contraction of forested areas is a world-wide process which affects the tropical belt too. It is no surprise that by the 20th century the growth of the regional runoff coefficient is general and this is reflected in the ever more frequent recurrence of major floods.

Our measurements in the Cserehát Hills underlined the other observations in Hungary according to which *in the completely forested catchments of low mountain type, 10 per cent loss deciduous forest area involves about another 5 per cent growth of the annual runoff coefficient.*

It is unfortunate that the rapid increase of runoff is not evenly distributed over the whole of the year. It was observed that in a local watershed of reducing forest cover, the more intensive rainfalls are, the higher is *the continentality of the runoff coefficient.* The result is that not only large amounts of water flow in river channels, but the range of the river regimes increases: discharge minima reduce in number and become more durable, while peak discharges exceeding the previous ones tend to be more frequent. As a whole, water regime begins more fluctuating and less predictable and to make it more even no other possibility exists than to build new barrages and reservoirs and to raise the heigths of levees.

The increasing frequency of floods of critical water discharge on the Great Plain rivers observed during the last decade or two is not the consequence of an increasingly humid climate but *results mainly from the changes in cultivation in the mountain watersheds* (particularly in the mountains of Romania).

The question is justified by the above: do we have to receive all the outlined consequences with acquiescence or can we do anything against the adverse tendencies and how? We are convinced that there are efficient methods to avoid the increase of troubles. Among them the more effective and coordinated international cooperation in land use may belong in many cases. First of all, however, with knowledge of the disclosed trends of landscape evolution, regulatory systems of landscape ecology which are capable to ensure the coordination of accelerated social progress and landscape utilization into a new balance with the natural forces should be elaborated. An opportunity sounds obvious: *to establish barrages on the uppermost Hungarian sections of the rivers with dammed reservoirs of proper size to retain sediment equal to at least 100–150 year fluvial load.* As it is known, intermediate lakes deprive any stream from its sediment load.

The reservoirs of sedimentation proposed to be built in the vicinity of the national border, however, do not only avoid the siltation of the active flood-plains of the rivers, but would multiply the life-time and functioning period of reservoirs of other purposes along the lower reaches of the rivers (e.g. the Kisköre, the Nagymaros and the Csongrád lakes — partly completed and partly proposed). It would highly improve the *amortization calculations* of the reservoirs themselves and their additional investments as well as the connected irrigation network and power plants too. It is an urgent task, since in the Kisköre reservoir, for instance, dozens of centimetres of silt layers are observed in some sections and there are points where the silt accumulation reaches the figure of 3–4 m per year (!) and, consequently, permanent silt extraction is necessary.

For these reasons, it has to be decided in the stage of preliminary planning or even during the conception of the project whether a reservoir is to be built or a trap for sediment, which would turn into a swamp in the future. In the perspective the two functions are impossible to reconcile in any establishments in Hungary, where streams have transported vast amounts of debris and soil derivates from the mountain watersheds to the lowland stream sections. Our investigations have proved: this activity can only increase in our days, since it is a corollary of the natural process of social progress and of the grow rightful demands against nature.

In conclusion, enormous efforts were made in the Great Plain to overcome rivers, to drain swamps and marshlands, to build irrigation systems and to plough land and nature was faced, in this way the geographical conditions of economic welfare and cultural growth were ensured for the millions of people who live here. The transformation of the natural environment, however, is not yet completed in the Great Plain. It perhaps will not ever stop. Since new responses are received from nature to the disturbance of the million year geographical trends and balances of inexhaustable and renewable landscape energies. The battle initiated by Man, who was successful in the first attack keeps on with nature and some encounters may turn out less favourable for us. The victories achieved so far in the reformation and 'domestication' of landscape energies are, consequently, hardly sufficient to found the faith of safety that our landscape already serves the winner with all of its energies.

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